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Aerotherm Final
Report No. 70-15

IMPROVED HEAT-SHIELD DESIGN PROCEDURES FOR MANNED ENTRY SYSTEMS

Part I
Executive Summary

Aerotherm Report No. 70-15, Part I
Copy No. ____

FINAL REPORT

IMPROVED HEAT-SHIELD DESIGN PROCEDURES FOR MANNED ENTRY SYSTEMS

Part I
Executive Summary

Prepared for

National Aeronautics and Space Administration

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Contract NAS9-9494

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NASA Manned Spacecraft Center
Houston, Texas
Structures and Mechanics Division
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FOREWORD

This report was prepared by Aerotherm Corporation under NASA Manned Spacecraft Contract NAS9-9494. The contract period of performance was from 22 May 1969 through 22 May 1970. The report is published in two parts:

Part I : Executive Summary

Part II: Application to Apollo

A number of computer code user's manuals were also prepared and published as separate reports.

The sponsor of the program was the Thermal Protection Section, Structures and Mechanics Division, Manned Spacecraft Center, National Aeronautics and Space Administration, Houston, Texas. Mr. Donald M. Curry and Miss Emily W. Stephens were the NASA/MSC technical monitors. The Aerotherm program manager and principal investigator was Mr. Eugene P. Bartlett.

An advanced heat shield design procedure has been developed which should ultimately prove very useful to the space shuttle program and other potential flight vehicles of the 1970's and 1980's. The design procedure consists of a set of computer programs for analyzing the thermal protection system, including in-depth material response; the boundary layer which flows over the surface; and interaction between the material and its environment, including ablation when applicable. These codes are easy to use and reliable, they contain sophisticated thermophysical models, and they have broad applicability - yet, the computation times are sufficiently short to warrant their use in design-oriented studies. These computational tools represent a significant advance in the state-of-the-art in aerothermodynamics and thermal protection system design analysis.

The most significant advance is in the treatment of the chemically reacting turbulent (or laminar) boundary layer. This code applies to arbitrary body shapes and permits consideration of three-dimensional effects within the limitations of small boundary-layer crossflow.

These design procedures have been subjected to a large amount of wind-tunnel and flight data, principally for Apollo, with excellent success. Agreement with calorimeter data, thermocouple data, and ablation and char sensor data has consistently been good. Most noteworthy here is the excellent agreement of wind tunnel as well as flight convective heating data for Apollo at incidence, including transitional and turbulent heating in the flight application. Auxiliary uses of the boundary layer program have been

- the development of transition correlations making use of the detailed boundary-layer profile information provided by the code;
- the development of corrections for applying wind-tunnel heating data to flight;
- the development of correlations for turbulent heating distributions;
- the development of blowing corrections applicable to positions around the body and to turbulent flow as well as to the stagnation region.

These efforts are described in detail in Part II of this series of reports.

The development of this heat shield design procedure has taken place over the past five years. The present contract is the third in a series of contracts which have been conducted for NASA Manned Spacecraft Center to develop improved heat-shield design procedures. Some funding has been provided from other sources as well. Under Contract NAS9-4599 the initial development of the basic codes was performed. Under Contract NAS9-6719 the boundary layer code was extended to turbulent flow (with joint sponsorship of the Air Force Weapons Laboratory under Contract F29601-68-C-0062), the reliability of the codes was improved, and preliminary application to Apollo was made. Under the present contract, the codes were improved still further, extensively applied to Apollo wind-tunnel and flight data, and synthesized into a self-consistent heat shield design procedure. A list of the final technical reports which have been prepared under these contracts is presented at the end of this report.

A number of government organizations in addition to the NASA Manned Spacecraft Center have acquired recent or earlier versions of the various component codes. These include the following:

1. NASA Langley Research Center
   Various reentry research and development programs
2. NASA Ames Research Center
   Various research studies including shock interaction in inlets and transpiration cooling over cones
3. NASA Lewis Research Center
   Material response studies
4. Jet Propulsion Laboratory
   Planetary entry studies
5. Sandia Corporation
   Extensive reentry research and design activities
6. Air Force Materials Laboratory
   Ballistic reentry nose tip technology problems
7. Air Force Weapons Laboratory
   Electron distributions over antenna windows with upstream ablation
8. Air Force Rocket Propulsion Laboratory
   Rocket nozzle heat transfer analysis and design and combustion studies
9. Naval Weapons Center, China Lake, California
   Ablation in rocket motors
10. Naval Ordnance Laboratory, White Oak, Maryland
    Fundamental ablation studies
11. Naval Postgraduate School, Monterey, California
    Unsteady flow over compressors

While the codes have seen broad application as shown by the above listing, the major heat-shield design analysis studies have been limited to those conducted by Aerotherm and Sandia Corporation. Further application of the codes is needed to qualify them for future flight programs. In particular, further attention should be paid to validation of the turbulent heating model under hypersonic flow conditions. Also, the procedure should be extended to permit consideration of completely three-dimensional inviscid and boundary layer flows.

FINAL TECHNICAL REPORTS

Contract NAS9-4599

Kendall, R.M., et al: An Analysis of the Coupled Chemically Reacting Boundary Layer and Charring Ablator, June 1968.

Part I , Summary Report, NASA CR-1060.

Part II , Finite Difference Solution for the In-Depth Response of Charring Materials Considering Surface Chemical and Energy Balances, NASA CR-1061

Part III, Nonsimilar Solution of the Multicomponent Laminar Boundary Layer by an Integral Matrix Method, NASA CR-1062.

Part IV, A Unified Approximation for Mixture Transport Properties for Multicomponent Boundary-Layer Applications, NASA CR-1063.

Part V, A General Approach to the Thermochemical Solution of Mixed Equilibrium-Nonequilibrium, Homogeneous or Heterogeneous Systems, NASA CR-1064.

Part VI, An Approach for Characterizing Charring Ablator Response with In-Depth Coking Reactions, NASA CR-1065.

Contract NAS9-6719

Bartlett, E.P., et al: Further Studies of the Coupled Chemically Reacting Boundary-Layer and Charring Ablator, October 1968.

Part I, Summary Report, NASA CR-92471.

Part II, An Evaluation of Surface Recession Models for the Apollo Heat Shield Material, NASA CR-92472.

Part III, A Non-grey Radiation Transport Model Suitable for Use in Ablation-Product Contaminated Boundary Layers, NASA CR-92473.

Part IV, Nonsimilar Solution of An Incompressible Turbulent Boundary-Layer by an Integral Matrix Method, NASA CR-92474.

Contract NAS9-9494

Bartlett, E.P., et al: Improved Heat-Shield Design Procedures for Manned Entry Systems, Aerotherm Report No. 70-15, June 1970.

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